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(71) Applicant: AM INTERNATIONAL INCORPORATED
333 West Wacker Drive Suite 900
Chicago Illinois 60606-1265(US)

(72) Inventor: Temple,Stephen
66 Girton Road Cambridge
Cambs. CB3 OLN(GB)

(74) Representative: Coleman, Stanley et al
MATHYS & SQUIRE 10 Fleet Street
London EC4Y 1AY(GB)

(54) High density multi-channel array, electrically pulsed droplet deposition apparatus.

(57) A high density multi-channel array, electrically pulsed droplet deposition apparatus comprises a sheet of piezoelectric material poled in a direction normal to said sheet and formed with a plurality of parallel channels mutually spaced in an array direction normal to the length of said channels. Each channel is defined by a pair of facing side walls and a bottom surface extending between the respective side walls. A top sheet facing said bottom surfaces of said channels and bonded to said side walls closes the channels at their tops. Each of the channels is further formed with a forvard part of uniform depth between the bottom surface and the top sheet and a part rearwardly of the forward part of lesser depth than the forward part. Each of at least some of the side walls of the forward parts include electrodes on opposite sides thereof to form shear mode actuators for effecting droplet expulsion from the channels associated with the actuators. Each electrode extends substantially along the length of the corresponding side wall and over an area from the edge of the side wall adjoining the top sheet which is so spaced from the bottom surface of the channel in which the electrode is disposed as to leave the portion of the wall adjacent the bottom surface of the channel substantially free from elastic distortion when an electric field is applied across the electrodes of the associated wall.

Fig.2.

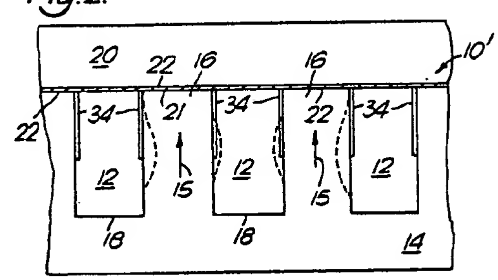
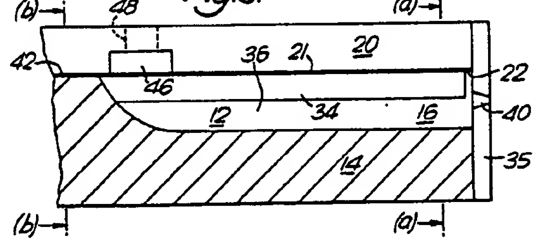


Fig.3.



EP 0 364 136 A2

High Density Multi-Channel Array, Electrically Pulsed Droplet Deposition Apparatus.

This invention relates to electrically pulsed, droplet deposition apparatus and more particularly to such apparatus in the form of a high density multi-channel array. A familiar use to which apparatus of this kind is put is as a drop-on-demand ink jet printhead.

A high density array printhead should clearly have the property that each channel can be actuated separately and that a minimum of the energy applied to one channel is coupled into neighbouring channels. Energy coupling between channels is termed, "crosstalk".

In co-pending European applications 88300144.8 (Publication No. 0 277 703A) and 88300146.3 (Publication No. 0 278 590A) there are disclosed ink jet printheads having a multiplicity of parallel channels mutually spaced in an array direction normal to the length of said channels which employ shear mode actuators which occupy side walls of the channels as the means of expelling droplets from nozzles respectively communicating with the channels. Shear mode actuators were chosen to avoid one kind of crosstalk, namely that arising from elastic interaction from stress waves through the piezo-electric material of the printhead caused by volume changes in the actuators. Shear mode actuators when actuated do not experience a volume change, for example, a change in length or height thereof.

Actuation of two groups respectively of odd and even numbered channels, alternately is a further feature of shared, shear mode wall actuators as disclosed in co-pending European Application No. 88300146.3 (Publication No. 0 278 590A). Actuation of pressure p in a selected channel induces pressure -p/2 in the immediate neighbouring channels which cannot therefore be actuated at the same time as the selected channel. Pressure crosstalk namely energy coupling into the next but one, next but three etc., channels, i.e. the neighbouring channels of the same group, also occurs when compliant channel wall actuators of the selected channel are actuated. This can be avoided by means of the offset form of channel arrangement disclosed in the said co-pending European application.

Although crosstalk reduction has been effected in the ways described for the forms of crosstalk referred to, a further source of crosstalk has been identified which is troublesome and requires a different approach to accomplish its reduction. The shear mode wall actuators of a printhead of the kind referred to, when actuated, are subject to respective fields normal to electrodes on opposite sides of channel facing walls which comprise the actuators. These fields give rise to fringe fields which in the vicinity of the roots of the wall actuators have significant components parallel to the poling direction so that the piezo-electric material in these regions is volumetrically distorted rather than being deflected in shear.

The overall effect of these fringe fields is to deflect the base material at the roots of the wall actuators to induce crosstalk into the neighbouring channels and at the same time to reduce significantly the wall actuator deflection. It is a principal object of the present invention, therefore, to provide a high density, multi-channel array, electrically pulsed droplet deposition apparatus in which cross talk attributable to fringe field effects arising upon actuation of shear mode channel actuators is minimised.

The present invention consists in a high density multi-channel array, electrically pulsed droplet deposition apparatus, comprising a bottom sheet of piezo-material poled in a direction normal to said sheet and formed with a multiplicity of parallel, open topped channels mutually spaced in an array direction normal to the length of the channels and defined each by facing side walls and a bottom surface extending between said side walls, a top sheet facing said bottom surfaces of said channels and bonded to said side walls to close said channels at the tops thereof, respective nozzles communicating with said channels for the ejection of droplets of liquid therefrom, connection means for connecting said channels with a source of droplet deposition liquid and electrodes provided on opposite sides of each of some at least of said side walls to form shear mode actuators for effecting droplet expulsion from the channels associated with said actuators, each electrode extending substantially along the length of the corresponding side wall and over an area so spaced from the bottom surface of the channel in which the electrode is disposed as to leave substantially free from piezo-elastic distortion adjacent thebottom surface of the channel the bottom sheet adjacent the wall on which said electrode is provided when an electric field is applied across the electrodes of said wall.

Preferably, each electrode extends over an area of the side wall on which it is provided from an edge of said side wall adjoining said top sheet.

Advantangeously, each channel is formed with a forward part of uniform depth between said bottom surface and said top sheet, and a part rearwardly of the forward part of lesser depth than said forward part, said rearward part being formed on the facing side wall and bottom surfaces thereof

with an electrically conductive coating in electrical contact with the electrodes on the facing side walls of the forward part of the channel.

In one form of the invention the electrodes on the facing walls of the forward part of each channel are formed in one with the electrically conductive coatings on the channel part rearwardly of said forward part.

Suitably, the depth of the coating on the side walls is approximately half the depth of the forward part of the channel and covers the bottom part of the channel rearwardly of said forward part.

In another form of the invention said top sheet is formed in generally like manner to said bottom sheet, of piezo-electric material with channels corresponding to said channels of said bottom sheet and with electrodes on side walls of channels thereof corresponding with the side walls of said bottom sheet which are provided with electrodes, said top sheet being disposed in inverted relation to said bottom sheet and secured thereto so that each pair of said corresponding channels of the sheets together form a single composite channel extending within each of said sheets and said nozzles are provided in a nozzle plate secured to said sheets to provide respective nozzles at an end of said composite channels.

In an alternative way of achieving a similarly functioning apparatus, said bottom sheet comprises an integral sheet of piezo-electric material having oppositely poled regions respectively in upper and lower parts of each channel side walls and said electrodes extend on opposite sides of each of some at least of the said channel side walls from the top of said side walls, each said electrode covering said region in the upper part and a substantial part of said region in the lower part of the corresponding channel side wall. In this arrangement the top sheet is made of insulating material.

The invention further consists in the method of making a high density, multi-channel array pulsed droplet deposition apparatus, characterised by forming a bottom sheet with a layer of piezo-electric material poled normal to said layer, forming a multiplicity of parallel, open topped, droplet liquid channels in said bottom sheet which extend partially through said layer of piezo-electric material to afford walls of piezo-electric material between successive channels, forming electrodes on respective opposite sides of some at least of said walls which extend from the top of said walls to a location spaced from the bottom of said walls so that an electric field can be applied to effect shear mode displacement of said walls provided with electrodes in a direction transversely to said channels, connecting electrical drive circuit means to said electrodes, securing a top sheet to said walls to close said channels and providing nozzles and droplet liquid supply means for said channels, said electrodes being formed on a substantial length of said walls and so spaced from the bottom of said walls as to leave substantially free from elastic distortion, adjacent the bottom surfaces of the channels, the walls on which said electrodes are provided when an electric field is applied by way of said electrodes transversely to said walls.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

FIGURE 1 is a fragmentary diagrammatic sectional view to an enlarged scale of a high density, multi-channel array, electrically pulsed, droplet deposition apparatus in the form of an ink jet printhead which illustrates the problem addressed by the present invention;

FIGURE 2 is a view, similar to Figure 1, showing an ink jet printhead according to the invention;

FIGURE 3 is a fragmentary longitudinal sectional view of an ink channel of one form of ink jet printhead according to the invention;

FIGURES 4(a) and 4(b) are fragmentary sectional views taken on the lines (a)-(a) and (b)-(b) of Figure 3;

FIGURE 5 is a view similar to Figure 3, of another form of ink jet printhead according to the invention;

FIGURE 6 is a view similar to Figure 2 showing a further form of ink jet printhead according to the invention;

FIGURE 7 is a view similar to Figures 2 and 6 showing a further form of ink jet printhead according to the invention; and;

FIGURE 8 is a view of an alternative form of a component used in the embodiments of the invention shown in Figures 2 and 7.

In the drawings, like parts are given the same reference numerals.

Referring to Figure 1, an ink jet printhead 10 comprises a multiplicity of parallel ink channels 12 forming an array in which the channels are mutually spaced in an array direction perpendicular to the length of the channels. The channels are formed at a density of two or more channels per mm. in a sheet 14 of piezo-electric material, suitably PZT, poled in the direction of arrows 15 and are defined each by side walls 16 and a bottom surface 18, the thickness of the PZT being greater than the channel depth. The channels 12 are open topped and in the printhead are closed by a top sheet 20 of insulating material - shown in Figure 2, but not in Figure 1 where it is omitted to make clearer the problem associated with the arrangement of Figure 1 - which is thermally matched to the sheet 14 and is disposed parallel to the surfaces 18 and bonded by a bonding layer 21 to the

tops 22 of the walls 16. The channels 12 on their side wall and bottom surfaces are lined with a metallised electrode layer 24. It will be apparent therefore that when a potential difference of similar magnitude but opposite sign is applied to the electrodes on opposite faces of each of two adjacent walls 16, the walls will be subject to electric fields indicated by lines of flux density 26 in opposite senses normal to the poling direction 15. The walls are in consequence deflected in shear mode, and in the absence of a top sheet 20 are displaced to the positions indicated by the broken lines 28. However at the roots of the side walls, the electric fields 26 exhibit fringe effects such that the lines of force have substantial components in the direction of poling. Where in piezo-electric material the electric field lies in the direction of poling i.e. the 3 direction, the material suffers an elongation or contraction both in the 3-3 direction along and in the 3-1 and 3-2 directions normal to the poling direction. In contrast a shear mode deflection arises when the electric field in the 1 direction is perpendicular to the direction of poling where the 1-5 deflection is rotational in character and is normal to both the field and the poling axes and is not accompanied by any change in height or length of the sidewalls thus deflected. The chain dotted lines 32 show a swelling caused by the fringe field lines 26 in the piezo-electric material which is a maximum at the mid-channel locations of those channels which are electrically activated and a contraction which is a maximum in the middle of those channels adjacent the activated channels.

In a printhead as described the channels are arranged in two groups of odd and even numbered channels and selected channels of each group are activated simultaneously and alternately with the channels of the other group. The fringe fields then give rise to distortions in the base sheet 14. These reduce the shear mode deflection of the walls 16 and generate stresses piezo-elastically which are elastically propagated and develop crosstalk in the adjacent channels.

Alternatively, the channels may be arranged in three or more groups of interleaved channels with selected channels of one group being simultaneously actuated in sequence with selected channels of the other groups. Whether arranged in two or more groups it will be apparent that between actuated channels there are a number of unactuated channels which is at least one less than the number of channel groups. Cross-talk is then substantially reduced but the loss of shear mode wall deflection in the root of the wall remains significant.

Referring now to Figures 2 and 3, the channels 12 therein are provided on facing walls 16 thereof with metallised electrodes 34 which extend from the edges of the tops 16 of the walls down the walls to a location well short of the bottom surface 18 of the channels. There is an optimum metallisation depth which gives maximum wall displacement at about the mid-height of the walls depending on the distribution of wall rigidity. The virtue of this design is that the fringe fields damp out rapidly within the walls 16 where they generate stresses but no resultant deflection in the walls. At the roots of ttle walls there are no fringe fields so that there are no field components in the poling direction and therefore no distortion of the kind shown by the line 32 in Figure 1 takes place.

In Figure 3, it will be seen that the channels 12 comprise a forward part 36 of uniform depth which is closed at its forward end by a nozzle plate 38 having formed therein a nozzle 40 from which droplets of ink in the channel are expelled by activation of the facing actuator walls 16 of the channel. The channel 12 rearwardly of the forward part 36 also has a part 42 of lesser depth extending from the tops 22 of the walls 16 than the forward part 36. The metallised plating 34 which is on opposed surfaces of the walls 16 occupies a depth approximately one half that of the channel side walls but greater than the depth of the channel part 42 so that when plating takes place the side walls 16 and bottom surface 18 of the channel part 42 are fully covered whilst the side walls in the forward part 36 of the channel are covered to approximately one half the channel depth in that part. A suitable electrode metal used is an alloy of nickel and chromium, i.e. nichrome. It has been found that for satisfactory actuation of the actuator walls 16 the compliance of the bond layer 22 which is $\frac{hE}{He}$ where h is the height of the bond layer 22, e is the modulus of elasticity of that layer, H is the height of the walls 16 and E the elastic modulus thereof, should be less than 1 and preferably less than 0.1.

It will be noted that a droplet liquid manifold 46 is formed in the top sheet 20 transversely to the parallel channels 12 which communicates with each of the channels 12 and with a duct 48 which leads to a droplet liquid supply (not shown).

Cutting of the channels 12 in the sheet 14 is effected by means of grinding using a dicing cutter of the kind disclosed in co-pending European Patent Application No. 88308515.1 or United Kingdom Patent Application No. 8911312.0. The cutter is rotated at high speed and is mounted above a movable bed to which a number of the poled PZT sheets are secured. The bed is movable with respect to the horizontal rotary axis of the cutter in parallel with that axis and in two mutually perpendicular axes a vertical and a horizontal axis both at right angles to the horizontal axis parallel with the cutter axis. The pitch of the cutter blades is greater than the pitch required for the channels

12 so that two or more passes of the cutter are needed to cut the channels 12. At each cut the forward channel sections 36 are first cut and the bed is then lowered so that the sections 42 of the channels are cut to the lesser depth required. The minimum concave radius at rear end of section 36 of the channels is determined by the radius of the cutter blades.

Referring now to Figures 4(a) and 4(b) in connection with which the manner of depositing the metal, suitably nichrome, electrodes 34 is described: For this operation a collimated beam 60 of evaporated metal atoms is derived from an electron beam which is directed on a metal source located about 0.5 to 1.0 metres from the jig holding the PZT sheets 14 in which the channels 12 have been cut. The PZT sheets 14 contained in ttie jig are located with respect to the metal vapour beam so that the vapour emission makes an angle of $+\delta$ with the longitudinal vertical central plane of the channels 12. In this way metal deposition takes place on one side wall 16 of each channel to a depth, determined by the angle δ which is approximately half the depth of the section 36 of the channel but greater than the depth of the channel sections 42. The coating of a side wall 16 in each of the channel sections 36 is accompanied by coating of the corresponding wall in the sections 42 and of the greater part of the bottom surface of each of those sections. A second stage of the coating to complete the metal deposition is effected by turning the sheets 14 through 180° so that the incident angle of the metal vapour is now $-\delta$, and the walls 16 facing those already coated are treated and the coating of bottom surfaces of channel sections 42 is also completed. Excess metal on the tops and ends of the channel walls is removed by lapping. Instead of reversing the sheets 14 two sources of metal vapour may be used in succession to effect the metal coatings.

After plating of the channels 12 is effected and before connection thereof to a suitable driver chip, an inert inorganic passivant is coated on the walls of the channel sections 36 and 42. The passivant coating is chosen to have a high electrical resistivity and is also resistant to migration of ion species from the droplet fluid, in the case of a printer, the ink, to be employed, under the shear mode actuator field. A plurality of passivant layers may be needed to obtain the requisite electrical properties. Alternating films of Si_3N_4 and SiON are suitable for the averred purpose.

Figure 5 shows an alternative design to that of Figure 3 in which a thinner sheet 14 of PZT is employed which is laminated by a bond layer 51 to a base layer 50 suitably of glass thermally matched to the sheet 14. The base layer here contains an ink manifold 52 communicating with the channels and with a source of droplet liquid supply. The channels 12 are formed a little less deep than the PZT sheet to help stiffen the bond layer 51 in the forward part 36 i.e. the active part of the channels.

Referring now to Figure 6, the invention is illustrated as applied to the form of printhead 10, described with reference to Figures 2(a) to (d) in co-pending European Patent Application 88300146.3 (Publication No. 0 278 590). Thus, similar upper and lower sheets 14 of piezo-electric material are formed with corresponding channels 12 provided with metallised electrodes 34 and are secured together by inverting the upper sheet with respect to the lower sheet and providing the bond layer 22 between the tops of the corresponding channel side walls. In this form of actuation, because the directions of poling are opposed in the sheets the channel side walls are deflected into chevron form.

The electrodes 34 stop short of the bottom of the channels, as in the case of the embodiment of the invention illustrated in Figure 2, so that fringe field effects producing field components in the direction of poling are reduced, if not eliminated.

It will be apparent that manufacture is facilitated by making the sheets 14 of identical form.

Referring now to the embodiment illustrated in Figure 7, a sheet 14 is employed therein having upper and lower regions poled in opposite senses as indicated by the arrows 15. The electrodes 34 are deposited so as to cover the facing channel side walls from the tops thereof down to a short distance from the bottoms of the channels so that a region of each side wall extending from the top of the channel and poled in one sense and a substantial part of a lower region of the side wall poled in the reverse sense are covered by the relevant electrode. Thus, it will be appreciated that the arrangement described operates to deflect the channel side walls into chevron form as in the case of the embodiment of the invention described with reference to Figure 6, though in the case of the presently described embodiment the chevron deflection occurs in a monolithic sheet of piezo-electric material rather than two such sheets bonded on or near the plane containing the channel axes. The manner of poling of a sheet 14 of piezo-electric material transversely thereto with regions of opposed polarity at opposite sides of the sheet is described in co-pending European patent application No. 88308514.4 (Publication No. 0 309 147).

Figure 8 illustrates a sheet 20′ of insulating material which can be employed as an alternative to sheet 20 of the embodiments of the invention illustrated in Figures 2 and 3, 5, 6 and 7. Sheet 20′ is formed with shallow channels 12′ which correspond to the channels 12 of sheet 14 and is bonded after inversion thereof to the sheet 14, the

bond layer 22 being formed between the tops of the corresponding channel side walls in the sheets 14 and 20′.

It will be noted that, as described in connection with Figure 5, a sheet 50′ of glass or other insulating material is employed as a stiffening means for the sheet 14 of piezo-electric material. Such a stiffening sheet can also be employed to stiffen the sheet 14 in the arrangements of Figures 2 and 3 and to stiffen both sheets 14 in the arrangement of Figure 6.

Claims

1. A high density multi-channel array, electrically pulsed droplet deposition apparatus, comprising a bottom sheet of piezo-material poled in a direction normal to said sheet and formed with a multiplicity of parallel, open topped channels mutually spaced in an array direction normal to the length of the channels and defined each by facing side walls and a bottom surface extending between said side walls, a top sheet facing said bottom surfaces of said channels and bonded to said side walls to close said channels at the tops thereof, respective nozzles communicating with said channels for the ejection of droplets of liquid therefrom, connection means for connecting said channels with a source of droplet deposition liquid and electrodes provided on opposite sides of each of some at least of said side walls to form shear mode actuators for effecting droplet expulsion from the channels associated with said actuators, each electrode extending substantially along the length of the corresponding side wall and over an area so spaced from the bottom surface of the channel in which the electrode is disposed as to leave substantially free from piezo-elastic distortion adjacent the bottom surface of the channel the bottom sheet adjacent the wall on which said electrode is provided when an electric field is applied across the electrodes of said wall.

2. A high density multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 1, characterised in that each electrode extends over an area of the side wall on which it is provided from the edge of said side wall adjoining said top sheet.

3. A high density multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 2, characterised in that said area is rectangular.

4. A high density multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any preceding claim, characterised in that said electrodes extend from an end of said channels adjacent said nozzles.

5. The apparatus of Claim 2 or 3 wherein each of said channels is formed with a forward part of uniform depth between said bottom surface and said top sheet in which said electrodes are provided and a part rearwardly of said forward part of lesser depth than said forward part.

6. The apparatus of Claim 5 wherein the electrodes provided on the facing walls of each of said forward parts have a depth which is greater than the depth of said rearward parts but less than the depth of said channels.

7. The apparatus of Claim 6 wherein each of said rearward parts is formed with an interior electrically conductive coating which is in electrical contact with the electrodes on the facing side walls of the forward parts of said channels.

8. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 5, characterised in that the electrodes on the facing walls of the forward part of each channel are formed in one with the electrically conductive coatings on the channel part rearwardly of said forward part.

9. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any preceding claim, characterised in that said electrodes are provided on respective facing side walls of each of said channels.

10. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 9, characterised in that electrical connections to said electrodes of each of said channels are provided to enable operation of said channels in a plurality of groups of interleaved channels, selected channels of each of said groups being simultaneously actuated in sequence with selected, simultaneously actuated channels in the other or each of the others of said groups so that between any two actuated channels there is disposed at least one unactuated channel.

11. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 10, characterised in that electrical connections to said electrodes of each of said channels are provided to enable operation of said channels in two groups of interleaved alternating channels, selected channels of one of said groups being simultaneously actuated in sequence with selected, simultaneously actuated channels in the other of said groups.

12. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any preceding claim, characterised in that said top sheet is formed in generally like manner to said bottom sheet, of piezo-electric material with channels corresponding to said channels of said bottom sheet and with electrodes on side walls of channels thereof corresponding with the

side walls of said bottom sheet which are provided with electrodes, said top sheet being disposed in inverted relation to said bottom sheet and secured thereto so that each pair of said corresponding channels of the sheets together form a single composite channel extending within each of said sheets and said nozzles are provided in a nozzle plate secured to said sheets to provide respective nozzles at an end of said composite channels.

13. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 12, characterised in that said top and bottom sheets are of identical form.

14. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in Claim 12 or Claim 13, characterised in that said top and bottom sheets are bonded to respective stiffening layers of insulating material.

15. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any one of Claims 1 to 11, characterised in that said bottom sheet comprises an integral sheet of piezo-electric material having oppositely poled regions respectively in upper and lower parts of each channel side walls and said electrodes extend on opposite sides of each of some at least of the said channel side walls from the top of said side walls, each said electrode covering said region in the upper part and a substantial part of said region in the lower part of the corresponding channel side wall.

16. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any one of Claims 1 to 11 and 15, characterised in that said bottom sheet is bonded to a stiffening layer of insulating material.

17. A high density, multi-channel array, electrically pulsed droplet deposition apparatus as claimed in any one of Claims 1 to 11 and 15 and 16, characterised in that said top sheet is formed with channels corresponding with said channels of said bottom sheet and said top sheet is bonded to said bottom sheet so that each pair of corresponding channels of the sheets together form a single composite channel.

18. The method of making a high density, multi-channel array pulsed droplet deposition apparatus, characterised by forming a bottom sheet with a layer of piezo-electric material poled normal to said layer, forming a multiplicity of parallel, open topped, droplet liquid channels in said bottom sheet which extend partially through said layer of piezo-electric material to afford walls of piezo-electric material between successive channels, forming electrodes on respective opposite sides of some at least of said walls which extend from the top of said walls to a location spaced from the bottom of said walls so that an electric field can be applied to effect shear mode displacement of said walls provided with electrodes in a direction transversely to said channels, connecting electrical drive circuit means to said electrodes, securing a top sheet to said walls to close said channels and providing nozzles and droplet liquid supply means for said channels, said electrodes being formed on a substantial length of said walls and so spaced from the bottom of said walls as to leave substantially free from elastic distortion, adjacent the bottom surfaces of the channels, the walls on which said electrodes are provided when an electric field is applied by way of said electrodes transversely to said walls.

19. The method claimed in Claim 18, characterised by forming said electrodes by deposition of metal from metal vapour beams directed towards said walls at an angle to channel facing surfaces thereof.

Fig.1.

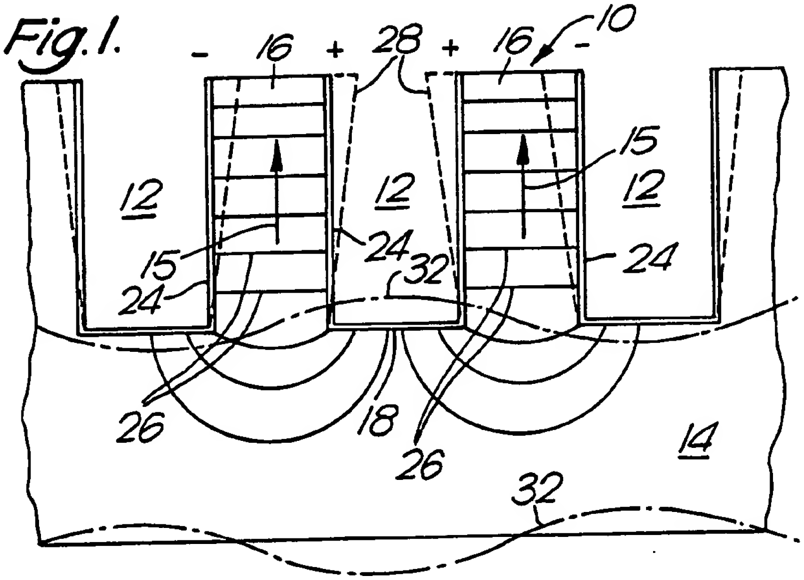


Fig.2.

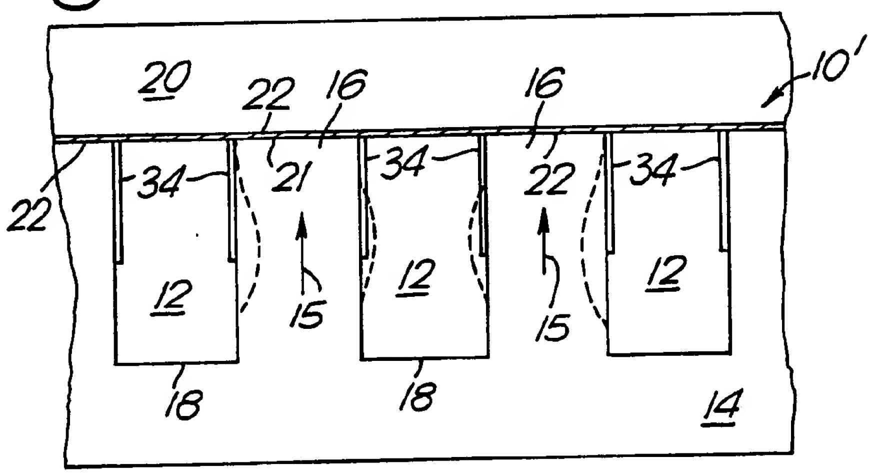


Fig.3.

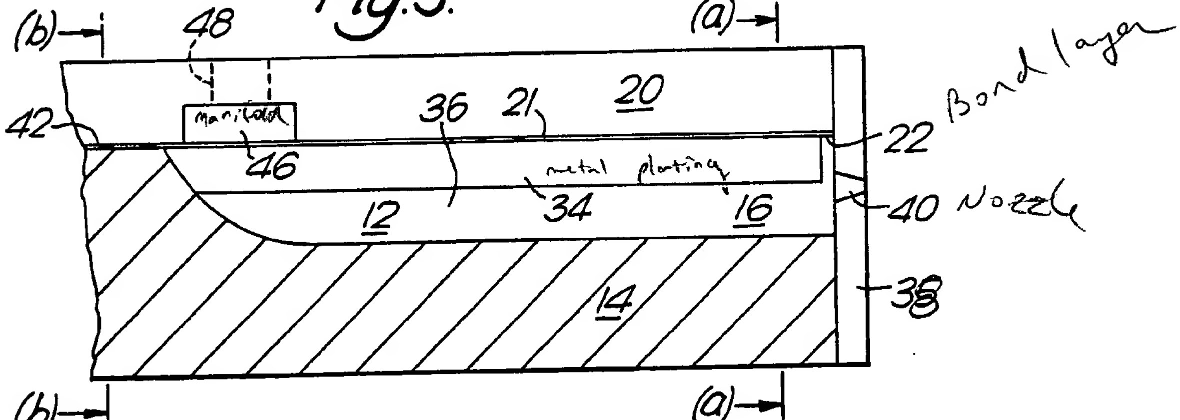


Fig.4(b).

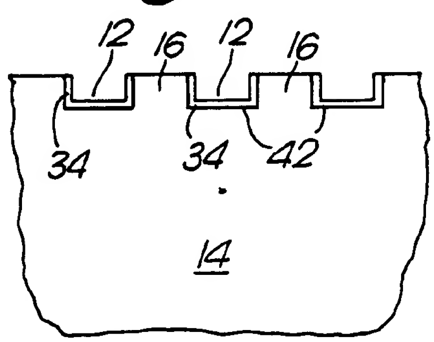


Fig.4(a).

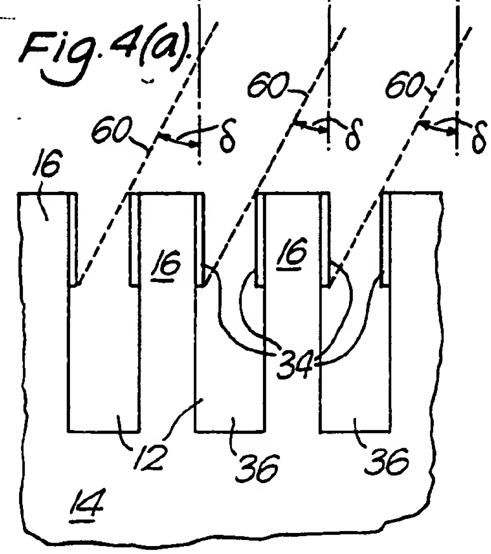


Fig.5.

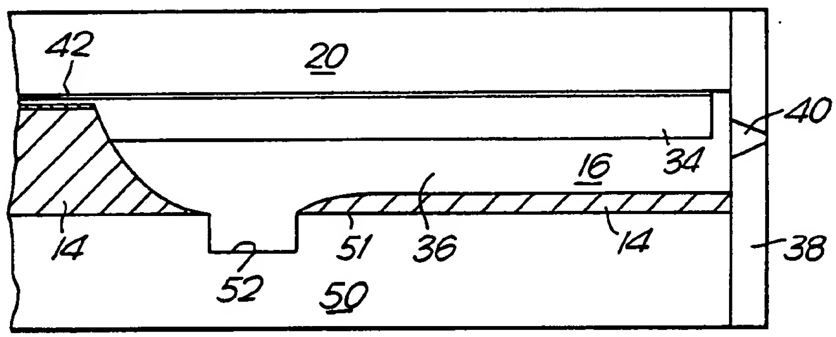


Fig.6.

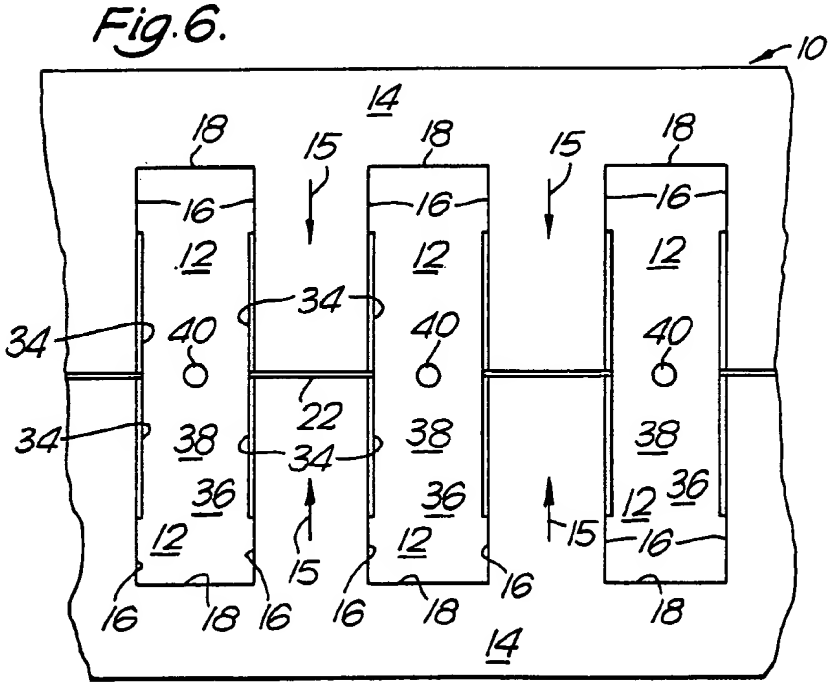


Fig. 7.

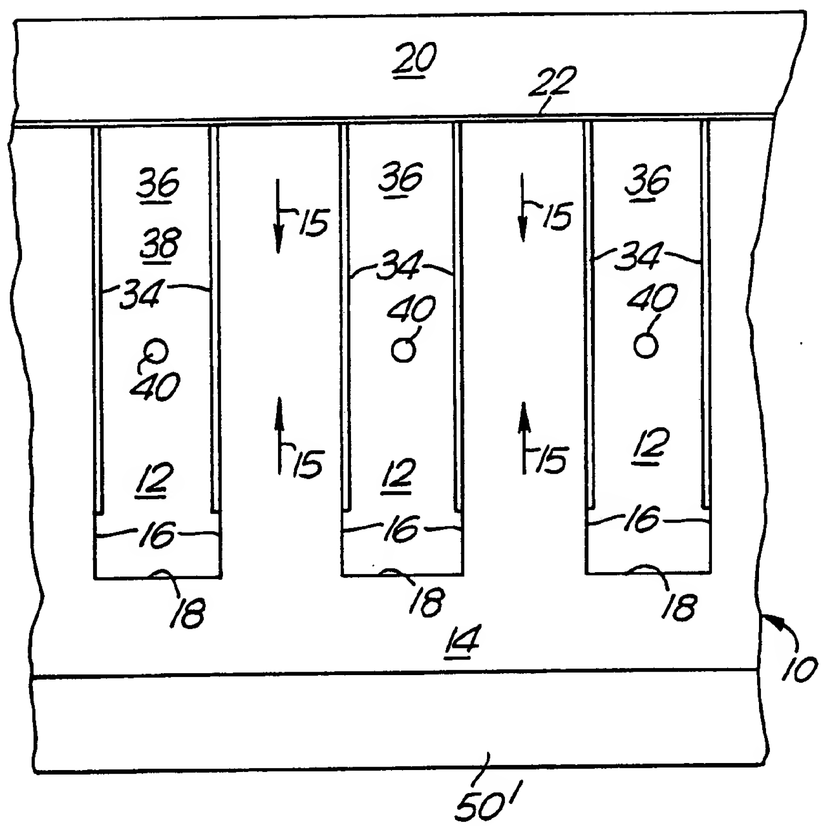


Fig. 8.